National Aeronautics and Space Administration

countdown!

NASA Space Shuttles and Facilities

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Cover photo: Twin columns of fire from the solid rocket boosters hurl Space Shuttle Atlantis off Launch Pad 39B into the sky for a rendezvous with the International Space Station on mission STS-115. Clouds of smoke and steam spread across the pad and the fixed service structure at left, topped by the lightning mast. Mission STS-115 was the 116th space shuttle flight, the 27th flight for orbiter Atlantis, and the 19th U.S. flight to the International Space Station. During the mission, Atlantis' astronauts delivered and installed the 17.5-ton, bus-sized P3/P4 integrated truss segment on the station.

Below: The 525-foot-tall Vehicle Assembly Building dominates the view in the Launch Complex 39 Area at Kennedy Space Center. Farther in the background is Launch Pad 39B. The Banana River, Banana Creek and turn basin flow through and around the grounds. On the horizon is the Atlantic Ocean.

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The first flight of the commercially developed SPACEHAB laboratory module begins with the flawless liftoff of the Space Shuttle Endeavour from Launch Pad 39B on June 21, 1993.

Space Shuttles

NASA explores for answers that power our future. The space shuttle is NASA's reusable manned space vehicle designed for the transport of people, spacecraft and equipment to and from the International Space Station. The shuttle comprises three major flight elements:

1) The orbiter, which is a reusable delta-winged spaceplane, is about the size and shape of a DC-9 jet, with three reusable liquid-fueled main engines. It has a design life of 100 missions.

The original fleet in the order the orbiters were first flown are Columbia, OV-102, (1981); Challenger, OV-099, (1983); Discovery, OV-103, (1984); Atlantis, OV-104, (1985); and Endeavour, OV-105, (1992). Challenger was destroyed Jan. 28, 1986, during launch. Columbia was lost Feb. 1, 2003, while returning from research mission STS-107.

The orbiters are named after pioneering sea vessels that established new frontiers in research and exploration. Only the orbiters have names, and an orbiter alone is not a full space shuttle.

2) The external tank contains liquid hydrogen and liquid oxygen for the orbiter's three main engines. It is the only major element not recovered and reused.

3) Two solid rocket boosters, called SRBs, filled with solid propellant burn in unison with the orbiter's engines at liftoff. They are designed for reuse on at least 20 missions, and are recovered at sea after separation.

The space shuttle has remained the only NASA-operated manned space vehicle into the 21st century.

In addition to its normal workload of scientific satellites and space science missions, the shuttle fleet of three vehicles is the primary transport into orbit for the segments of the International Space Station.

Russia has used its own vehicles to launch some space station components, and so may some of the other partners.

The space station has been continuously manned since Nov. 2, 2000. Prior to that time, America had maintained a continuous presence in space on Space Station Mir by an agreement with Russia that allowed astronauts to rotate turns of duty.

The first space shuttle lifted off from Pad A on Launch Complex 39 at Kennedy Space Center on April 12, 1981.

After a two-day, test-flight mission that verified the ability of the orbiter Columbia to function in space, it landed at Edwards Air Force Base in California. The vehicle was piloted by John Young and Robert Crippen. The STS-1 mission marked the first time that a new space vehicle carried a crew on its initial flight.

An assembled space shuttle is approximately 184 feet (56 meters) long, 76 feet (23 meters) high to the tip of the orbiter's vertical tail, and 78 feet (24 meters) wide, measured across the orbiter's wingtips. Liftoff weight is usually about 4.5 million pounds (2,041,200 kilograms).

An orbiter's three liquid-fueled engines — drawing propellants from the external tank — and the two solid propellant rocket boosters burn simultaneously for the first two minutes. Together, they produce almost 7 million pounds (31.1 million newtons) of thrust at liftoff.

After two minutes of flight, a space shuttle reaches an altitude of 32 miles (51 kilometers) and the boosters have burned all their propellant. They then detach and parachute into the ocean. Two waiting ships recover them for refurbishment and reuse on later missions.

The orbiter and external tank continue on toward Earth orbit. When the orbiter's main engines cut off, the external tank is jettisoned, to re-enter the atmosphere and break up over a remote ocean area.

On most missions, the orbiter continues to coast, while still gaining altitude from the initial thrust, until it reaches the other side of the Earth from where the external tank was discarded.

Then the on-board orbital maneuvering engines fire to place the vehicle in a near circular, low-Earth orbit. Most operational missions last from seven to 10 days, though two weeks or more are not uncommon.

When the mission has been completed, the orbiter re-enters the atmosphere and returns to Earth, gliding to an unpowered landing at the Shuttle Landing Facility, or Edwards AFB if bad weather or other circumstances preclude landing at Kennedy.

Propellants

Sir Isaac Newton stated in his Third Law of Motion that "every action is accompanied by an equal and opposite reaction." A rocket operates on this principle. The continuous ejection of a stream of hot gases in one direction causes a steady motion of the rocket in the opposite direction.

A jet aircraft operates on the same principle, using oxygen in the atmosphere to support combustion for its fuel. The rocket engine has to operate outside the atmosphere, and so must carry its own oxidizer.

The gauge of efficiency for rocket propellants is specific impulse, stated in seconds. The higher the number, the "hotter" the propellant.

Specific impulse is the period in seconds for which a 1-pound (0.45-kilogram) mass of propellant (total of fuel and oxidizer) will produce a thrust of 1 pound (0.45- kilogram) of force. Although specific impulse is a characteristic of the propellant system, its exact value will vary to some extent with the operating conditions and design of the rocket engine. For this reason, different numbers are often quoted for a given propellant or combination of propellants.

Cryogenic

Cryogenic propellants are liquid oxygen, or LOX, which serves as an oxidizer, and liquid hydrogen, LH2, which is a fuel. The word cryogenic is a derivative of the Greek kyros, meaning "ice cold." LOX remains in a liquid state at temperatures of minus 298 degrees Fahrenheit (minus 183 degrees Celsius). LH2 remains liquid at temperatures of minus 423 degrees Fahrenheit (minus 253 degrees Celsius).

In gaseous form, oxygen and hydrogen have such low densities that extremely large tanks would be required to store them aboard a rocket. But cooling and compressing them into liquids vastly increase their density, making it possible to store them in large quantities in smaller tanks.

The high-efficiency engines aboard the space shuttle orbiter use liquid hydrogen and oxygen and have a specific impulse rating of 455 seconds. The fuel cells in an orbiter use these two liquids to produce electrical power through a process best described as electrolysis in reverse. Liquid hydrogen and oxygen burn clean, leaving a byproduct of water vapor.

The rewards for mastering LH2 are substantial. The ability to use hydrogen means that a given mission can be accomplished with a smaller quantity of propellants (and a smaller vehicle), or alternately, that the mission can be accomplished with a larger payload than is possible with the same mass of conventional propellants. In short, hydrogen yields more power per gallon.

Hypergolic

Hypergolic propellants are fuels and oxidizers that ignite on contact with each other and need no ignition source. This easy start and restart capability makes them attractive for both manned and unmanned spacecraft maneuvering systems. Another plus is their storability — they do not have the extreme temperature requirements of cryogenics.

The fuel is monomethyl hydrazine, or MMH, and the oxidizer is nitrogen tetroxide, or N2O4. Hydrazine is a clear, nitrogen/hydrogen compound with a "fishy" smell. It is similar to ammonia. Nitrogen tetroxide is a reddish fluid. It has a pungent, sweetish smell. Both fluids are highly toxic and are handled under the most stringent safety conditions.

The orbiter uses hypergols in its orbital maneuvering subsystem, known as OMS, for orbital insertion, major orbital maneuvers and deorbit. The reaction control system, or RCS, uses hypergols for attitude control.

The efficiency of the MMH/N2O4 combination in the orbiter ranges from 260 to 280 seconds in the RCS, to 313 seconds in the OMS. The higher efficiency of the OMS system is attributed to higher expansion ratios in the nozzles and higher pressures in the combustion chambers.

Solid

The solid-propellant motor is the oldest and simplest of all forms of rocketry, dating back to the ancient Chinese. It is a casing, usually steel, filled with a mixture of solid form chemicals (fuel and oxidizer) that burn at a rapid rate, expelling hot gases from a nozzle to achieve thrust.

Solids require no turbopumps or complex propellant feed systems. A simple squib device at the top of the motor directs a high-temperature flame along the surface of the propellant grain, igniting it instantaneously.

Solid propellants are stable and easily storable. Unlike liquid-propellant engines, though, a solid-propellant motor cannot be shut down. Once ignited, it will burn until all the propellant is exhausted.

Solids have a variety of uses for space operations. Small solids often power the final stage of a launch vehicle, or attach to payload elements to boost satellites and spacecraft to higher orbits.

Medium solids such as the payload assist module, or PAM, and the inertial upper stage, or IUS, provide the added boost to place satellites into geosynchronous orbit or on planetary trajectories.

The PAM-DII provides a boost for space shuttle payloads. The IUS goes on the space shuttle.

The space shuttle uses the largest solid rocket motors ever built and flown. Each reusable booster contains 1.1 million pounds (453,600 kilograms) of propellant, in the form of a hard, rubbery substance with a consistency like that of the eraser on a pencil.

A solid rocket booster is seen on the mobile launcher platform as part of the stack for Discovery and shuttle mission STS-92.

The four center segments are the ones containing propellant. The uppermost one has a star-shaped, hollow channel in the center, extending from the top to about two-thirds of the way down, where it gradually rounds out until the channel assumes the form of a cylinder. This opening connects to a similar cylindrical hole through the center of the second through fourth segments. When ignited, the propellant burns on all exposed surfaces, from top to bottom of all four segments.

Atlantis is in the Vehicle Assembly Building, where it has been stacked with the external tank and solid rocket boosters.

Since the star-shaped channel provides more exposed surface than the simple cylinder in the lower three segments, the total thrust is greatest at liftoff, and gradually decreases as the points of the star burn away, until that channel also becomes cylindrical in shape. The propellant in the star-shaped segment is also thicker than that in the other three.

A solid propellant always contains its own oxygen supply. The oxidizer in the shuttle solids is ammonium perchlorate, which forms 69.93 percent of the mixture. The fuel is a form of powdered aluminum (16 percent), with an iron oxidizer powder (0.07 percent) as a catalyst. The binder that holds the mixture together is polybutadiene acrylic acid acrylonitrile (12.04 percent). In addition, the mixture contains an epoxy-curing agent (1.96 percent). The binder and epoxy also burn as fuel, adding thrust.

The specific impulse of the space shuttle solid rocket booster propellant is 242 seconds at sea level and 268.6 seconds in a vacuum.

Facilities and Operations

Kennedy Space Center is the primary NASA center for the test, checkout and launch of space shuttle vehicles and their payloads, as well as the turnaround of orbiters between missions. It is the primary landing site for the shuttle.

Manned space shuttles launch from Kennedy's Launch Complex 39, located on Merritt Island, Fla., just north of Cape Canaveral. The Launch Complex 39 facilities originally supported the Apollo lunar landing program. From 1967 to 1975, 12 Saturn V/Apollo vehicles, one Saturn V/Skylab workshop, three Saturn 1B/Apollo vehicles for Skylab crews, and one Saturn 1B/Apollo for the joint U.S.-Soviet Apollo-Soyuz mission flew into space from Launch Complex 39.

These facilities underwent modifications to process and launch the space shuttle. Modifying existing facilities was far less expensive than building all new structures.

There were two major new additions — a special runway to land returning orbiters and an orbiter checkout hangar called the Orbiter Processing Facility. During the 1980s and 1990s, several new facilities were added for solid rocket booster processing, shuttle logistics, orbiter modification and refurbishment, and repair and final manufacture of thermal protection system materials.

Shuttle Landing Facility

When an orbiter lands at the Kennedy Space Center, it touches down on one of the world's longest runways. The concrete Shuttle Landing Facility is located northwest of the Vehicle Assembly Building on a northwest/southeast alignment.

Navigational aids on the ground and on board the orbiter help to direct it to a smooth landing. A microwave scanning beam landing system guides the final approach and brings the orbiter to the designated point on the runway.

Landings may be made from the northwest to southeast (Runway 15) or from the southeast to northwest (Runway 33).

Unlike conventional aircraft, the orbiter lacks propulsion during the landing phase. Its high-speed glide must bring it in for a landing perfectly the first time — there is no circle-and-try-again capability. The landing speed of the orbiter ranges from 213 to 226 miles (343 to 364 kilometers) per hour. A large drag chute helps slow the orbiter during rollout, greatly reducing wear on the wheel brakes.

The runway is about twice the length and width of those at most commercial airports. The landing strip is concrete and approximately 15,000 feet (4,572 meters) long. It has an asphalt overrun, 1,000 feet (305 meters) long, at each end.

Space Shuttle Endeavour is towed toward the "mate-demate device" following landing on runway 15 at KSC's Shuttle Landing Facility atop a modified Boeing 747 shuttle carrier aircraft.

The overruns have been strengthened so that they also could support the weight of a shuttle orbiter when landing. The runway is 300 feet (91.4 meters) wide, with 50-foot (15-meter) shoulders, also asphalt, which have been strengthened to support an orbiter.

The runway is 16 inches (40.6 centimeters) thick at the center, and slopes downward 24 inches (61 centimeters) both ways to the asphalt on each side. The concrete was originally cut with grooves, each 0.25 inch (0.63 centimeter) wide and deep, and 1.25 inches (3.2 centimeters) apart, from the center to the edges of the asphalt. The grooves and slope were thought to provide a very effective way to shed water, helping to prevent hydroplaning in wet weather. The grooves also provided a skid-resistant surface.

The first 3,500 feet (1,067 meters) at each end were later ground down to remove the grooves because of high abrasion levels on the tires at touchdown. Also, improvements were made to the landing zone light fixtures. In 1994, the entire runway surface was abraded to a smoother texture to further reduce tire wear.

A 550-by-490-foot (168-by-149-meter) aircraft parking apron, or ramp, is located at the southeastern end of the runway. On the northeast corner of the ramp is the mate/demate device which attaches the orbiter to or lifts it from the Shuttle Carrier Aircraft during ferry operations. There are movable platforms for access to some orbiter components.

The mate/demate device can lift up to 230,000 pounds (104,328 kilograms) and withstand winds of up to 125 miles (201 kilometers) per hour.

A diesel-driven towing tractor brings the orbiter to its next stop after landing, the Orbiter Processing Facility. Ground-cooling and air-purging transporters are still hooked up to the orbiter and travel behind the orbiter during the tow.

Orbiter Processing Facility

An orbiter is towed to the Orbiter Processing Facility within hours of its arrival, either after landing at Kennedy or returning aboard a ferry flight on the shuttle carrier aircraft.

The facility has three almost identical high bays, each of which is 197 feet (60 meters) long, 150 feet (46 meters) wide, 95 feet (29 meters) high, and encompasses a 29,000-square-foot (2,694 square-meter) area. A low bay connects high bays 1 and 2. It is 233 feet (71 meters) long, 97 feet (30 meters) wide and nearly 25 feet (eight meters) high.

High bay 3, built last, is located to the north and east of the first two; it also has an adjacent low bay. Annexes and portable buildings provide additional shop and

Processing for a mission begins when an orbiter is towed into one of three Orbiter Processing Facility bays at KSC.

office space. Each high bay comes equipped with a 30-ton (27-metric-ton) bridge crane with a hook height of approximately 66 feet (20 meters). Platforms, a main access bridge and two rolling bridges with trucks provide access to various parts of the orbiter. The trucks have a telescoping arm with rotatable buckets to hold workers. The high bays have an emergency exhaust system. The low bay contains areas for electronic, mechanical and electrical equipment, a communications room, offices and supervisory control rooms. All bays have fire protection systems.

In addition to routine post-flight servicing and checkout, many of the vehicle modifications needed for future flight requirements, or to enhance vehicle performance and correct deficiencies, are performed in the Orbiter Processing Facility.

Spacecraft or payloads processed through checkout in a horizontal position, usually the larger ones such as space station elements, are installed in the orbiter in this facility. Spacecraft or payloads handled in a vertical position normally are installed at the launch pad.

After processing, the orbiter is usually towed into the Vehicle Assembly Building transfer aisle through the large door at the north end of the high bay to facilitate mating with the solid rocket booster/external tank stack.

Atlantis rolls to the Vehicle Assembly Building.

Thermal Protection System Facility

A thermal protection system, composed of a network of tiles, gap fillers and insulation blankets, protects the exterior of each orbiter from the searing heat of launch and re-entry, and the cold soak of space. These materials can sustain damage during a flight and must be inspected, repaired, or sometimes replaced for the next mission.

Repair and final manufacture of the thermal protection system materials takes place in the two-story, 44,000-square-foot (4,088-square-meter) Thermal Protection System Facility. It is located across the street from the Orbiter Processing Facility bays 1 and 2.

Logistics Facility

The modern 324,640-square-foot (30,159-square-meter) Logistics Facility is located south of the Vehicle Assembly Building. It contains about 150,000 space shuttle hardware parts and about 330 NASA and contractor workers.

An unusual feature of the Logistics Facility is the state-of-the-art parts retrieval system, which has automated handling equipment to find and retrieve specific parts.

Launch Equipment Test Facility (LETF)

The testing site for launch-critical ground support systems and equipment such as the orbiter access arm, external tank gaseous oxygen vent arm, external tank vent line, tail service masts and umbilical systems, and SRB holddown posts. It is designed to simulate launch vehicle events such as movement from wind, orbiter ignition and liftoff, effects of solar heating and cryogenic shrinkage.

The Multi-Payload Processing Facility (MPPF)

The Multi-Payload Processing Facility, or MPPF, was constructed in 1995 and is located in the Industrial Area. The facility is 19,647 square feet (1,825 square meters) in area and can accommodate one or more payloads in processing at the same time depending on their size. The facility supports the checkout assembly payload processing program. The MPPF has a high bay and a low bay and is equipped with a 20-ton overhead crane. In addition, the MPLM Access Certification Equipment , or MACE, training unit is located inside the MPPF. The MACE is an exact replica of the U.S.-made Unity module on the space station and is used to support training activities for the Space Station Processing Facility.

Space Station Processing Facility (SSPF)

This is the central preflight checkout and processing point for flight hardware elements of the International Space Station. Known as the SSPF, it is three stories tall with 457,000 square feet (42,455 square meters) of space, including 63,000 square feet (5,853 square meters) dedicated to payload processing with a high bay and intermediate bay.

The test, control and monitor system, or TCMS, controls prelaunch testing and checkout for space station elements. The SSPF also includes communications and electrical control areas, laboratories, logistics staging areas, operational control rooms, office areas and a cafeteria. A 5,000-square-foot (464 square-meter) airlock is adjacent to the processing area, both of which are class-100,000 clean work area environments.

Vertical Processing Facility (VPF)

This 26,940 square-foot (2,503 square-meter) facility processes and integrates vertical payloads and upper stages. It contains cargo integration test equipment , or CITE, for verification of orbiter/payload interfaces and is an environmentally controlled class-100,000 clean work area high bay and airlock. It has a high-bay ceiling height of 105 feet (32 meters) with usable floor space of 10,153 square feet (943 square meters), two bridge cranes with combined lift capacity of 35 tons (31.7 metric tons) and a monorail crane of 10 tons (.1 metric ton) that services the airlock. Its six fixed platforms for spacecraft handling are serviced by a 2-ton (1.8-metric-ton) hoist.

Solid Rocket Booster Processing Facilities

After the space shuttle launches, the two solid rocket boosters burn out and jettison about two minutes into the flight. Huge parachutes lower them into the Atlantic Ocean where special recovery vessels retrieve and tow them back to a dock at Cape Canaveral Air Force Station.

Solid Rocket Booster Disassembly Facility: The area in and around Hangar AF and the hangar building itself together make up the Solid Rocket Booster Disassembly Facility. Special handling equipment located behind Hangar AF lifts the solid rocket boosters from the water. There, they undergo an initial washing. Each booster disassembles into four main segments and aft skirt and forward skirt assemblies. The main casing segments are cleaned, taken back to Launch Complex 39 at Kennedy and placed on railroad cars for shipment to the manufacturer where they are reloaded with propellant.

The truck delivering part of the equipment to be used on mission STS-109 moves into the Vertical Processing Facility at Kennedy.

Solid Rocket Booster Assembly and Refurbishment Facility: Refurbishment and subassembly of inert solid rocket booster hardware, including the forward and aft skirt assemblies, takes place in this facility, located south of the Vehicle Assembly Building. This complex has seven buildings — manufacturing, engineering and administration, service, hot fire testing, structures storage, modular office and chiller facility. The three-level manufacturing building includes an automated checkout system, an 80-by-200-foot (24-by-61-meter) high bay, two 15-ton (14-metricton) bridge cranes, and three overhead gantry robots; the latter are among the world's largest.

Rotation Processing and Surge Facility: Located just north of the Vehicle Assembly Building, this facility receives new and reloaded solid rocket booster segments shipped by rail from the manufacturer. The complex includes a processing building and two surge buildings. Inspection, rotation and aft booster buildup occur in the processing building. Completed aft skirt assemblies from the Assembly and Refurbishment Facility integrate here with the booster aft segments. The two nearby surge buildings (so named because they hold the "surge" of new booster segments) store the solid rocket booster segments until they are moved to the Vehicle Assembly Building for integration with flight-ready components.

Parachute Refurbishment Facility: Originally built to process parachutes used in the Gemini manned space program, this facility in the Industrial Area has been modified for the space shuttle. The two vessels that recover the solid rocket boosters also retrieve the parachutes from the ocean, hauling them in on large reels. These reels are taken to this facility, where the parachutes are washed, dried and stored in canisters for eventual reuse.

Vehicle Assembly Building: The solid rocket booster segments are integrated here into complete flight sets, mated with the external tank and then the orbiter before being moved to the launch pad.

External Tank

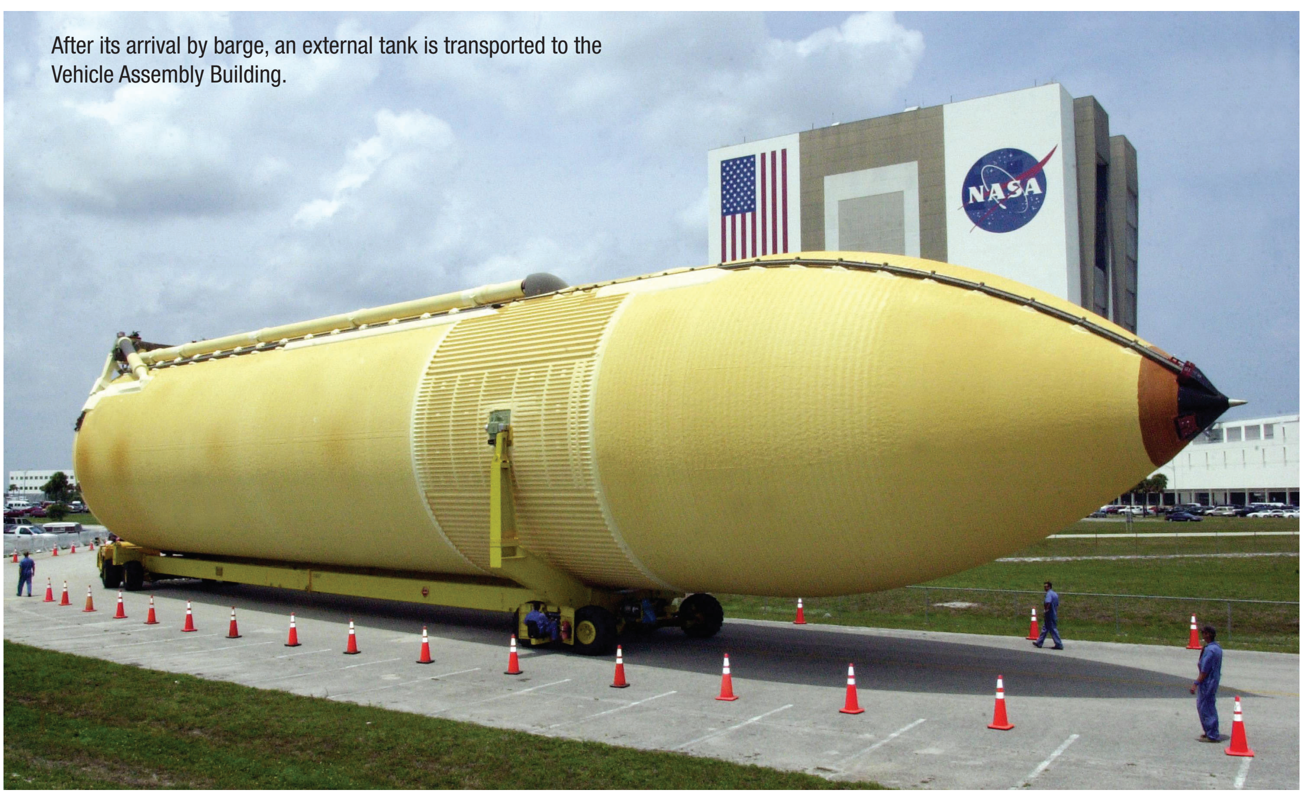
The external tank arrives by barge from its manufacturing site in Louisiana. Off-loaded at the Launch Complex 39 turn basin, it travels horizontally to the Vehicle Assembly Building. There, it is processed and stored in a vertical storage or checkout cell until mated with the other space shuttle flight elements.

When loaded, the external tank is the largest and heaviest element of the space shuttle. Besides containing and delivering propellants to the main engines, it serves as the structural backbone of the shuttle by absorbing the thrust loads during launch.

The tank has three major components: the forward liquid oxygen tank, an unpressurized intertank that contains most of the electrical components and joins the two propellant-filled tanks, and the aft liquid hydrogen tank.

The entire external tank is approximately 154 feet long (47 meters) and 28 feet (8.5 meters) in diameter. The liquid oxygen and hydrogen feed into the tank at the launch pad. These cryogenic propellants fuel the orbiter's three main engines during liftoff and ascent.

After the shuttle main engines shut down, the external tank separates from the orbiter and follows a ballistic trajectory into the Indian Ocean. It is the only major space shuttle component that is not recovered and reused.

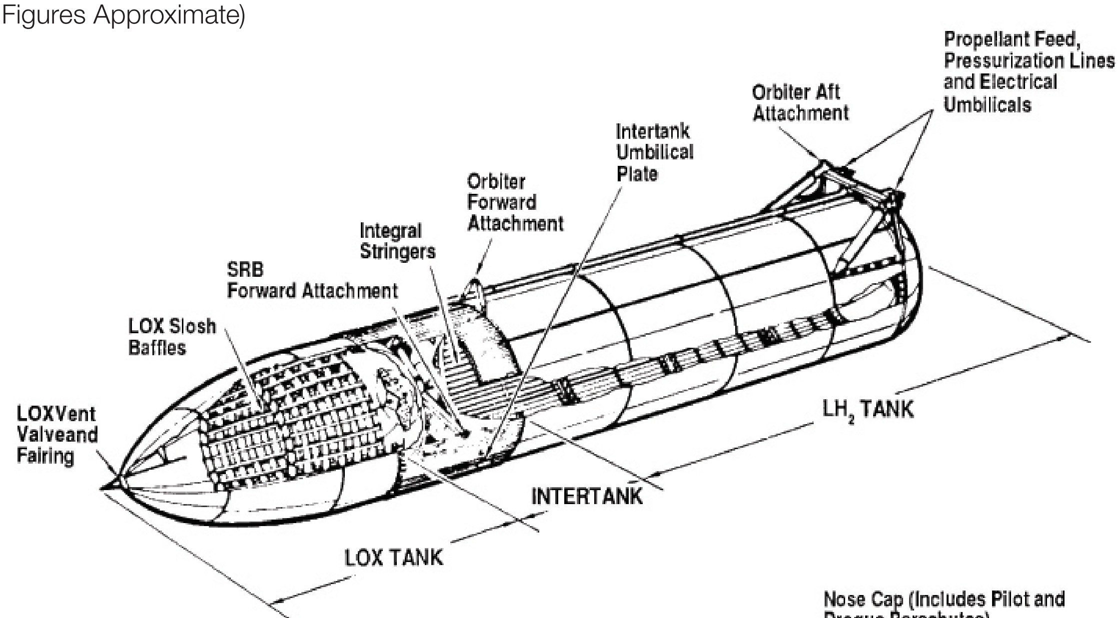


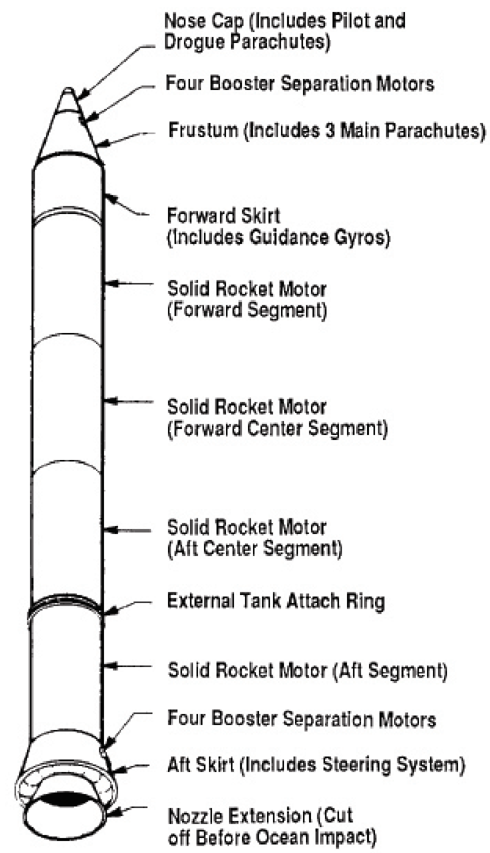
After its arrival by barge, an external tank is transported to the Vehicle Assembly Building.

External Tank

Length: ....154.2 feet (47 meters)
Diameter: .... 27.5 feet (8.4 meters)
Loaded Weight: ... 1,647,677 pounds (745,555 kilograms)
Empty Weight: ..... 58,500 pounds (26,470 kilograms)
LOX Tank: .... Maximum 143,351 gallons (542,641 liters)
LH2 Tank: .... Maximum 385,265 gallons (1,458,382 liters)

(All Figures Approximate)

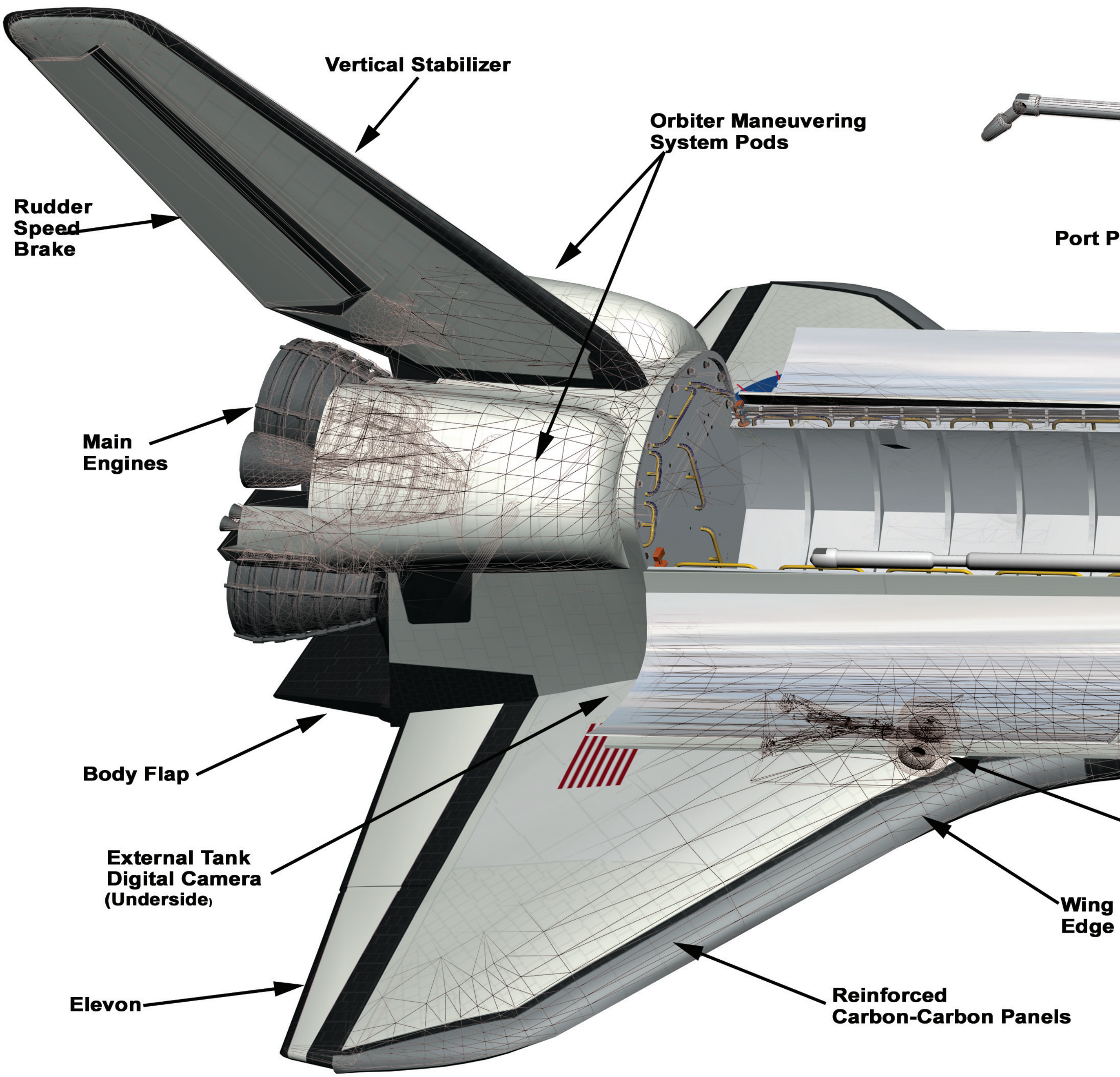


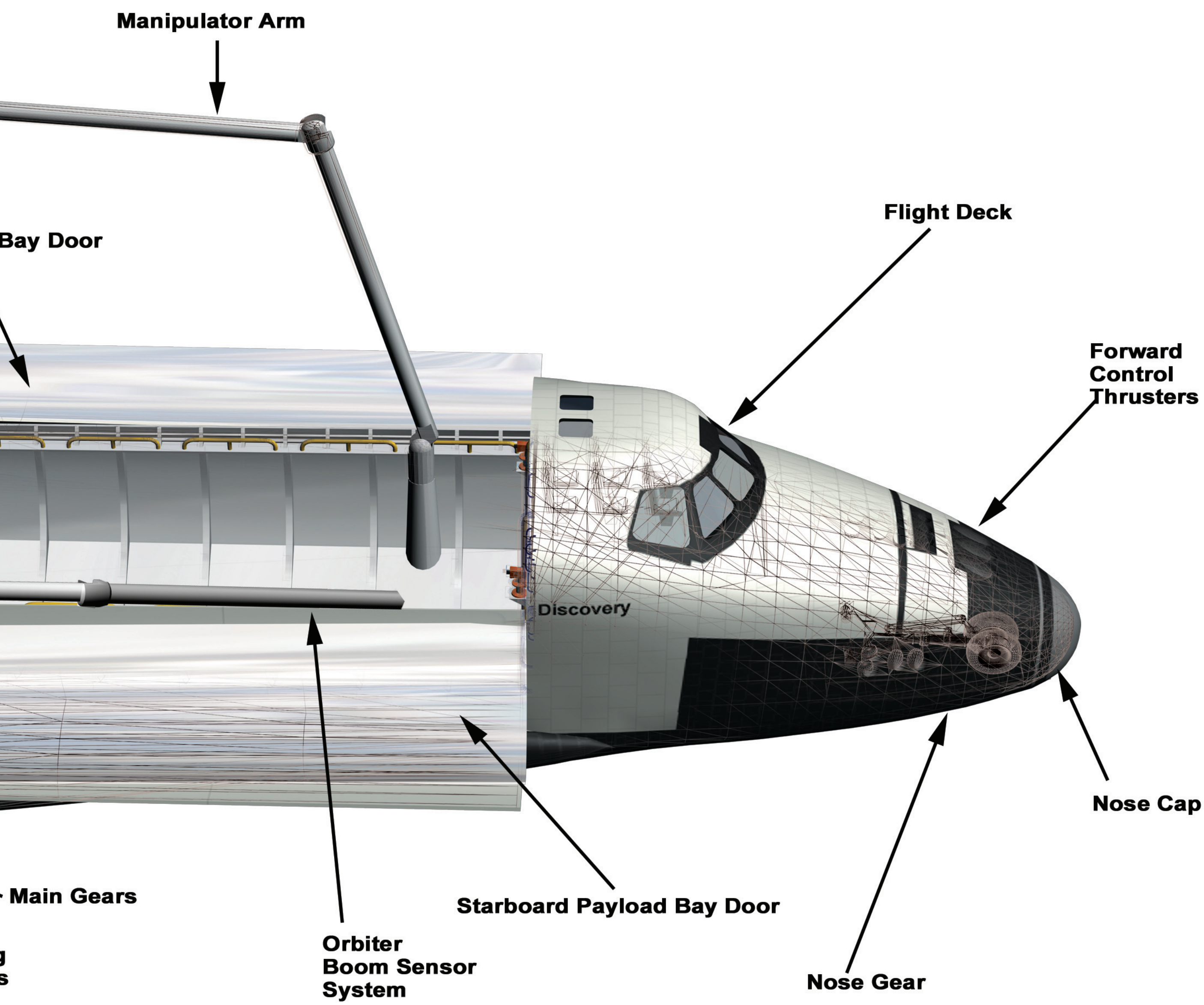


Solid Rocket Booster

Length: .... 149.2 feet (45.5 meters)
Diameter: .... 12.2 feet (3.7 meters)
Weight: .... 1.38 million pounds (6.3 million kilograms)
Liftoff Thrust .... Each 2.9 million pounds (12.9 million newtons)

(All Figures Approximate)


Vertical Stabilizer
Orbiter Maneuvering System Pods
Rudder Speed Brake
Port P
Main Engines
Body Flap
External Tank Digital Camera (Underside)
Elevon
Wing Edge
Reinforced Carbon-Carbon Panels


Manipulator Arm
Bay Door
Flight Deck
Forward
Control
Thrusters
Discovery
Main Gears
Orbiter
Boom Sensor
System
Starboard Payload Bay Door
Nose Gear
Nose Cap

Space Shuttle Main Engine Processing Facility (SSMEPF)

Newly arrived space shuttle main engines, delivered by truck from Stennis Space Center in Mississippi after test firing, off-load in the Space Shuttle Main Engine Processing Facility, known as the SSMEPF, in the Orbiter Processing Facility No. 3 Annex.

The SSMEPF is a 33,500-square-foot facility with six vertical stands and a 10-ton crane in the low bay and a 15-ton crane, drying bay and GSE storage in the high bay.

This processing facility can support engine building and engine processing post-flight (disassembly and reassembly, checkout and testing). The engines go to the OPF for installation.

The SSMEPF also supports engine removal operation and preparation for shipment back to Stennis for test firing, or to the manufacturer in California for refurbishment.

A cluster of three main engines provides the primary propulsion for the orbiter and helps to steer the shuttle. The liquid-hydrogen/liquid-oxygen propellant engines ignite on the ground and work in parallel with the SRBs during the initial ascent. After booster separation, the engines continue to operate for several minutes. They are the only reusable engines.

A 175-ton bridge crane in the Vehicle Assembly Building lifts Discovery to move it into high bay 3 for mating with the external tank and solid rocket boosters.

Vehicle Assembly Building (VAB)

At the heart of Launch Complex 39 is the huge Vehicle Assembly Building, one of the largest buildings in the world and the last stop for the shuttle before the launch pad. It covers a ground area of about eight acres (3.24 hectares) and has a volume of approximately 129,482,000 cubic feet (3,884,460 cubic meters). The VAB is 525 feet (160 meters) tall, 716 feet (218 meters) long, and 518 feet (158 meters) wide.

The structure can withstand winds of up to 125 miles (201 kilometers) per hour. The foundation rests on more than 4,200 steel pipe pilings, each 16 inches (40.6 centimeters) in diameter and driven down to bedrock at a depth of 160 feet (49 meters).

The high bay area is 525 feet tall (160 meters) and the low bay area is 210 feet (64 meters) tall. A north-south transfer aisle connects and transects the two bay areas.

Shuttle main engine maintenance takes place in the low bay, which also serves as a holding area for SRB forward assemblies and aft skirts.

Facing east are high bays 1 and 3 where integration and stacking of the complete space shuttle occurs in a vertical position on the mobile launcher platform. Facing west are high bays 2 and 4 where external tank checkout and storage takes place. High bay 2 also serves as a safe haven for a shuttle in the event of extreme weather conditions, such as a hurricane.

The VAB has more than 70 lifting devices, including two 325-ton (295-metric-ton) cranes.

During space shuttle buildup operations inside the VAB, SRB segments are transferred from nearby assembly and checkout facilities, hoisted onto a mobile launcher platform in high bays 1 or 3, and mated to form two complete boosters.

After checkout and inspection in high bays 2 or 4, the external tank transfers to high bays 1 or 3 to be attached to the SRBs. The orbiter, the final element, gets towed from the Orbiter Processing Facility to the VAB's transfer aisle, raised to a vertical position by overhead cranes, lowered onto the mobile launcher platform, and mated to the external tank.

With the assembly and checkout operations complete, the huge outer doors of the high bay open to permit the crawler-transporter to enter and move under the mobile launcher platform holding the assembled shuttle. The high bay doors are 456 feet (139 meters) high. The lower section is 152 feet (46 meters) wide and 114 feet (35 meters) high, with four door panels that move horizontally.

The upper door is 342 feet (104 meters) high and 76 feet (23 meters) wide, with seven door panels that move vertically.

Launch Control Center (LCC)

If the Vehicle Assembly Building is the heart of Launch Complex 39, then the Launch Control Center, known as the LCC, is its brain. The center is a four-story building connected to the east side of the Vehicle Assembly Building by an elevated, enclosed bridge.

The LCC contains two primary and one backup control rooms. Each is equipped with the launch processing system — an automated computer-operated system – which monitors and controls shuttle assembly, checkout and launch operations.

Largely because of the launch processing system, the countdown for a space shuttle launch (excluding built-in holds) takes only about 43 hours, compared to more than 80 hours needed for the earlier Apollo/Saturn flights.

Also, use of the launch processing system requires only approximately 225-230 people in the firing room compared to about 450 people needed for Apollo manned missions.

Mission responsibility transfers to the Mission Control Center at Johnson Space Center in Houston when the solid rocket boosters ignite at liftoff.

Transportable Equipment and Facilities

The **mobile launcher platform** , or MLP, is a two-story steel structure that provides a transportable launch base for the space shuttle. First used in the Apollo/Saturn program, the MLP underwent modifications for the shuttle.

The Launch Control Center faces both launch pads.

The main body of each MLP is 25 feet (7.6 meters) high, 160 feet (49 meters) long, and 135 feet (41 meters) wide. At their parking sites north of the Vehicle Assembly Building, in the Vehicle Assembly Building high bays and at the launch pads, the mobile launcher platforms rest on six pedestals 22 feet (6.7 meters) high.

Unloaded, an MLP weighs about 8.23 million pounds (3.73 million kilograms). With an unfueled shuttle aboard, it weighs about 11 million pounds (5 million kilograms).

The main body of the MLP provides three openings — two for the exhaust of the solid rocket boosters and one for the exhaust of the main engines.

There are two large devices called tail service masts, one on each side of the main engines exhaust hole. The masts provide several umbilical connections to the orbiter, including a liquid-oxygen line through one and a liquid-hydrogen line through another.

These cryogenic propellants feed into the external tank from the pad tanks via these connections. At launch, the umbilicals pull away from the orbiter and retract into the masts, where protective hoods rotate closed to shield them from the exhaust flames.

Each tail service mast assembly is 15 feet (4.6 meters) long and 9 feet (2.7 meters) wide, and rises 31 feet (9.4 meters) above the MLP deck. Other umbilicals carry helium and nitrogen, as well as ground cooling, purge air, electrical power and communications links.

Eight attach posts, four on the aft skirt of each SRB, support and hold the space shuttle on the MLP. These posts fit on counterpart posts located in the MLP's two solid rocket booster support wells. The space vehicle disconnects from the MLP by explosive nuts that release the giant studs linking the solid rocket attach posts with the MLP support posts.

Each mobile launcher platform has two inner levels containing electrical, test and propellant-loading equipment.

A **crawler-transporter** moves a fully assembled space shuttle, mounted on a mobile launcher platform, from the Vehicle Assembly Building to the launch pad. The huge tracked vehicles, originally used during the Apollo era, underwent modifications for the shuttle.

The two crawlers are about 20 feet (6.1 meters) high, 131 feet (40 meters) long, and 114 feet (34.7 meters) wide — about the size of a baseball diamond. Each one weighs about 6 million pounds (2.7 million kilograms) unloaded. A crawler has eight tracks, each with 57 shoes, or cleats,

A mobile launcher platform makes a test run on a crawler-transporter to the launch pad. Rising above the platform are the tail service masts.

each weighing approximately 1 ton (907 kilograms).

With a space shuttle aboard, the crawler can move at a maximum speed of about 1 mile (1.6 kilometers) an hour. Unloaded, it has a maximum design speed of 2 miles (3.2 kilometers) an hour, but in practice usually moves at the loaded speed.

The crawler has a leveling system designed to keep the top of the space shuttle vertical while negotiating the 5-percent grade leading to the top of the launch pad. Also, a laser docking system provides almost pinpoint accuracy when the crawler and MLP are positioned at the launch pad or in the Vehicle Assembly Building.

Two 2,750-horsepower diesel engines power each crawler. The engines drive four 1,000-kilowatt generators that provide electrical power to 16 traction motors. Operators in cabs on either end steer the giant vehicle.

The **crawlerway** is a 130-foot-wide (39.6-meter) roadway — almost as broad as an eight-lane freeway. The crawler-transporters use this for their more than 3-mile (4.8-kilometer) trek to one of the launch pads from the Vehicle Assembly Building.

The crawlerway consists of two 40-foot- (12-meter-) wide lanes, separated by a 50-foot- (15-meter-) wide median strip. The crawlerway has four layers to support the huge weight. The crawler, MLP and space shuttle with empty external tank weigh about 17 million pounds (7.7 million kilograms). The top layer of the crawlerway is river gravel about 8 inches (20.3 centimeters) thick on curves and 4 inches (10.2 centimeters) thick on straight-away sections. The other layers in descending order are 4 feet (1.2 meters) of graded, crushed stone; 2.5 feet (0.76 meter) of select fill; and 1 foot (0.30 meter) of compact fill. The journey from the Vehicle Assembly Building to one of the launch pads several miles away takes several hours.

The **payload canister** holds payloads in transit from various processing or assembly facilities to the launch pad (for vertically installed payloads) or to the Orbiter Processing Facility (for horizontally installed payloads).

Each environmentally controlled canister can carry payloads up to 15 feet (4.6 meters) in diameter and 60 feet (18.3 meters) long, matching the capacity of the orbiter payload bay. Maximum payload weight is approximately 65,000 pounds (29,484 kilograms).

The **payload canister transporter** is a 48-wheel, self-propelled truck that can transport the canister and its hardware either in a vertical or a horizontal position. It is 65 feet (19.8 meters) long and 23 feet (7 meters) wide, with a flatbed that can be lowered and raised from about 5 feet (1.5 meters) to 7 feet (2.1 meters) if required.

The crawler-transporter (6 million pounds) can lift the space shuttle on its mobile launcher platform (at a combined weight of about 11 million pounds) and move it to and from the launch pads. A crawler has eight tracks, each of which has 57 shoes or cleats. Each shoe weighs approximately 1 ton.

Independently steerable wheels permit the transporter to move forward, backward, sideways and diagonally, or turn on its own axis like a carousel. Diagonally opposed operator cabs are located on each end of the truck.

A diesel engine powers the transporter. Inside a spacecraft facility, it runs on an electric motor. Fully loaded, its top speed is about 5 miles (8 kilometers) per hour. But it can creep as slowly as 0.25 inch (0.635 centimeter) per second, or approximately 0.014 mile (0.022 kilometer) per hour, for payloads that require precise handling.

Launch Pads 39A and 39B

Launch Pads A and B at Complex 39 were originally designed for the Apollo program. They are octagonal in shape and virtually identical in size. Each covers about 0.25-square mile (0.65-square kilometer) of land, contained within a high chain-link fence.

The payload canister transporter can transport payloads in the canister either vertically or horizontally. On the launch pad (above), the canister is ready to be lifted up into the Payload Changeout Room on the rotating service structure.

Space shuttles launch from the top of the concrete hardstand, which measures 390 feet by 325 feet (119 meters by 99 meters). The Pad A stand has an elevation of 48 feet (14.6 meters) above sea level; Pad B, 55 feet (16.8 meters). There are six permanent and four extensible pedestals at each pad to support the MLP.

Lighting is provided by five clusters of xenon high- intensity searchlights (for a total of 40 searchlights) around the pad perimeter.

Each pad base required 68,000 cubic yards (52,000 cubic meters) of concrete. The ramp leading up to the pad surface is inclined at a 5-percent grade.

The two pads were heavily modified from their Apollo/Saturn V configuration to launch space shuttles. The upper portions of two of the three Saturn V launch umbilical towers were removed from the mobile launchers (which became mobile launcher platforms after this and other changes) and installed at each pad, to become fixed service structures, or FSS.

A **rotating service structure, or RSS**, which replaces the movable gantry in older designs, was built at each pad. And the movable Saturn V flame deflector in each flame trench was replaced with two joined and anchored shuttle flame deflectors.

The **fixed service structure** is located on the north side of each pad's hardstand. It is an open framework structure about 40 feet (12.2 meters) square. There are 12 work levels at 20-foot (6.1-meter) intervals.

The height of the structure to the top of the tower is 247 feet (75 meters), while the distance to the top of the fiberglass lightning mast is 347 feet (106 meters).

The FSS has three service arms:

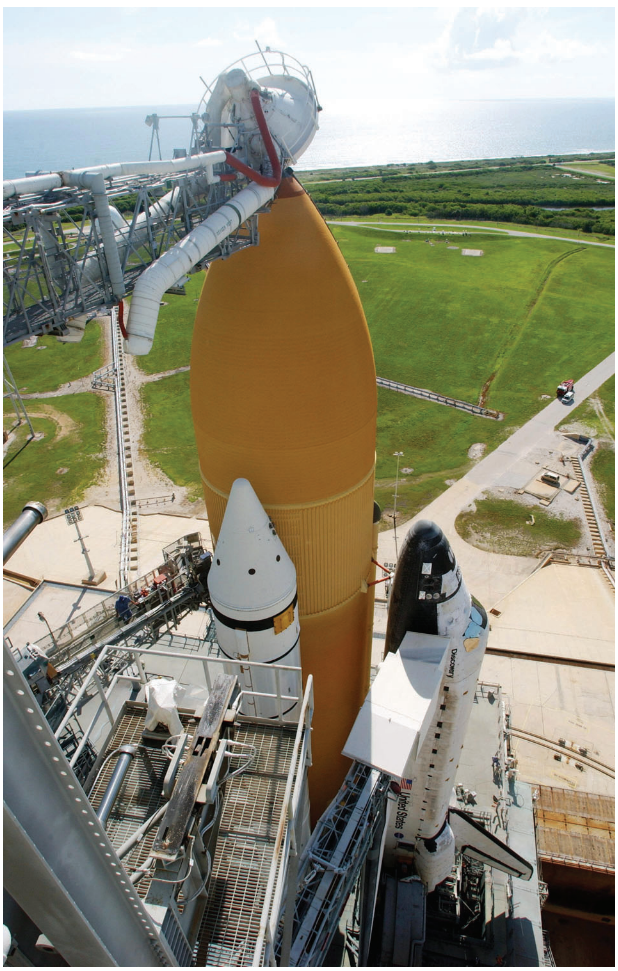
1. Orbiter Access Arm. This arm swings out to the crew access hatch on an orbiter, to provide entry for personnel. The outer end of this arm supports a small room, commonly called the "White Room," which can hold up to six persons.

A special White Room crew assists each astronaut crew in entering the space shuttle and secures the hatch. This arm remains in the extended position until 7 minutes and 24 seconds prior to launch, to provide an emergency exit for the crew should one be needed. It is 65 feet (19.8 meters) long, 5 feet (1.5 meters) wide, and 8 feet (2.4 meters) high.

The orbiter access arm is attached to the FSS at the 147-foot (44.8-meter) level. In an emergency, this arm can be mechanically or manually repositioned in about 15 seconds. It is covered with solid panels for fire protection, as well as a water spray system. The arm is also used for access to the mid-deck for late-in-the-count stowage of science experiments.

2. External Tank Hydrogen Vent Line and Access Arm. This system consists of two parts, a retractable access arm and a fixed support structure. It provides a means to mate the external umbilicals from the FSS to the tank, and access to the tank interior. The access arm supports small helium and nitrogen lines and electrical cables, all of which are located on an 8-inch-(20 centimeter-) diameter hydrogen vent line. The arm, which rotates 120 degrees to the stowed position in about three minutes, is retracted several hours before launch, leaving the umbilicals attached.

At SRB ignition, the umbilicals are released and retracted 33 feet (10.1 meters) into a latched position by a system of counterweights, where a curtain of sprayed water protects them from the engine flames. This activity takes just two seconds. The arm is 48 feet (14.6 meters) long, and attached at the 167-foot (51-meter) level.



The gaseous oxygen vent hood (at top), known as the "beanie cap," is located on the end of the highest swingarm attached to the Fixed Service Structure.

3. External Tank Gaseous Oxygen Vent Arm. This retractable arm supports a vent hood, commonly called the "beanie cap," that vacuums away the very cold liquid oxygen vapors as they boil off from the top of the external tank. It also supports associated systems such as heated gaseous nitrogen lines, the liquid oxygen vapor ducts, and electrical wiring.

The beanie cap is 13 feet (4 meters) in diameter, and the arm that supports it is 80 feet (24.4 meters) long, 5 feet (1.5 meters) wide, and 8 feet (2.4 meters) high. It attaches to the fixed service structure between the 207-foot (63-meter) and 227-foot (69-meter) levels.

When the beanie cap is swung into position on top of the external tank prior to loading propellants, two inflatable "accordion"-type seals cover the liquid oxygen vent openings. A heated gaseous nitrogen purge flows into the seal cavity, warming the very cold liquid oxygen vapors enough to prevent them from condensing into ice. If ice formed, it could dislodge and damage the tank, or orbiter insulation tiles and blankets, at liftoff. The beanie cap lifts to clear the external tank and the arm retracts starting 2 minutes and 30 seconds before engine ignition.

Hypergolic Umbilical System. This carries hypergolic fuel and oxidizer, as well as helium and nitrogen service lines, from the fixed service structure to the space shuttle.

The system also allows rapid connection of the lines to and disconnection from the vehicle. Six umbilical handling units, manually operated and controlled at the pad, attach to the rotating service structure. These units are located to the right and left sides of the aft end of the orbiter. They serve the orbital maneuvering system and reaction control system, as well as the payload bay and the nose area of the orbiter.

The **rotating service structure** provides protection for the orbiter and access to the cargo bay for installation and servicing of payloads at the pad. It pivots through one-third of a circle, to 120 degrees, from a retracted position well away from the shuttle to where its payload changeout room doors meet and match the orbiter cargo bay doors.

This structure rotates around a vertical hinge attached to one corner of the fixed service structure. The body of the rotating service structure begins at the 59-foot (18-meter) level and extends to 189 feet (57.6 meters) above the pad floor, providing orbiter access platforms at five levels. The hinge and a structural framework on the opposite end support the structure. This framework rests on two eight-wheel, motor-driven trucks, which ride on rails installed within the pad surface. The rotating body is 102 feet (31 meters) long, 50 feet (15 meters) wide and 130 feet (40 meters) high.

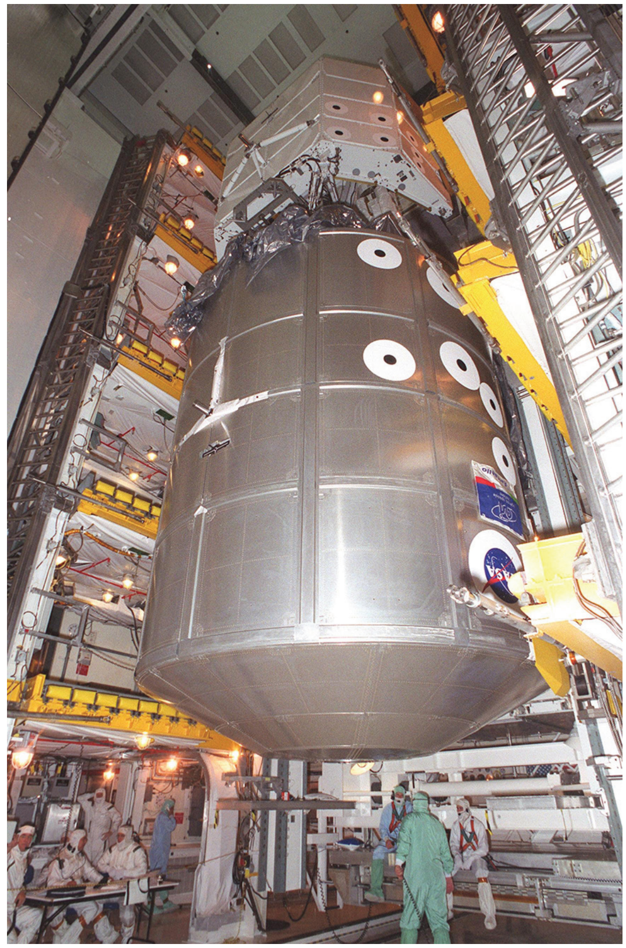
The primary purpose of the rotating service structure is to receive vertically installed space shuttle payloads while in the retracted position, rotate and install them in the orbiter cargo bay.

Payload Changeout Room: This is the major feature of the RSS. It is an enclosed, environmentally clean "White Room" that supports payload delivery and servicing at the pad and mates to the orbiter cargo bay for vertical payload installation. The environmental seals in the structure inflate against the sides of the payload canister. Clean, temperature- and humidity- controlled air purges the space between the closed doors of the RSS and the canister.

The canister and the RSS doors then close, the environmental seal deflates, and the canister lowers to the transporter to be taken off the pad. The RSS rolls into position to enclose the orbiter's payload bay, re-establishing the environmental seals and clean-air purge.

The payload is removed from the canister and later installed inside the orbiter cargo bay using the payload ground handling mechanism, or PGHM (pronounced "pig-um"). Five platforms are positioned at five levels to provide access to the payload when it is installed on the PGHM. Each platform has extendable planks that can be configured to accommodate a particular payload.

Orbiter Midbody Umbilical Unit: This provides access to and permits servicing of the midfuselage area of the orbiter. It extends from the rotating service structure at levels ranging from 158 to 176 feet (48 to 53.6 meters) above the pad surface, and is 22 feet (6.7 meters) long, 13 feet (4 meters) wide and 20 feet (6 meters) high. A sliding extension platform and a horizontally moving, line-handling mechanism offer access to the midbody umbilical door on the left side of the orbiter. Liquid oxygen and liquid hydrogen for the fuel cells, and gases such as nitrogen and helium, feed through this unit.



Two payloads – the Canadian robotic arm or Space Station Remote Manipulator System, and the Multi-Purpose Logistics Module Raffaello – are moved into the payload changeout room for mission STS-100.

A **weather protection system** at Pad A and Pad B shields the orbiter from windblown debris, heavy rains and hail that could damage the craft's thermal protection system tiles and insulation blankets. The rotating service structure, which closes around the orbiter while on the pad, shields a considerable portion of the vehicle. The weather protection system fills the gaps.

Metal doors that slide together between the orbiter's belly and the external tank provide protection for the lower portion of the orbiter. These doors, which measure up to 53 feet (16 meters) long and 38 feet (11.6 meters) tall, weigh up to 46,000 pounds (20,866 kilograms). They connect to the rotating service structure and the fixed service structure. The doors move together from opposite sides on wheeled flanges that ride on steel beams.

An inflatable seal that protects the top of the orbiter extends from the payload changeout room, forming a semicircle covering 90 degrees of arc between the vehicle and the external tank. A series of 20 or more bifold metal doors, about 80 by 4 feet (24.4 by 1.2 meters) in size, fold out from the payload changeout room on the rotating service structure to cover the side areas between the external tank and the orbiter.

The **flame trench and deflector system** protects the vehicle and pad structures from the intense heat of launch. It is located in the ground-level flame trench that bisects the hardstand. A flame deflector presents an inverted V-shape to the flames pouring into the trench through the openings in the mobile launcher platform.

Both sides of the upside-down V curve out near the bottom until they are almost horizontal. Flames follow these curves and deflect horizontally down the flame trench, rather than bouncing back to envelop the vehicle.

The flame trench divides the hardstand lengthwise from ground level to the pad surface. It is 490 feet (149 meters) long, 58 feet (18 meters) wide and 40 feet (12 meters) high. At launch, flames shoot out both ends of the trench into the air. The deflector for the space shuttle is actually a two-in-one device, where one side of the inverted V receives the flames from the orbiter's main engines, and the opposite side gets the flames from the two solid rocket boosters. It is fixed near the center of the trench and extends completely across it.

The orbiter and booster deflectors are built of steel and covered with an ablative material about 5 inches (12.7 centimeters) thick that flakes off to shed heat. These deflectors weigh more than 1 million pounds (453,600 kilograms) each.

In addition to the fixed deflectors, two movable ones are located at the top of the trench for additional protection from the solid rocket booster flames.

Also located in the landing zone is a bunker, with an M-113 armored personnel carrier stationed nearby.

The **lightning mast** extends above the fixed service structure and provides a "cone of protection" over the vehicle and pad structures. A steel cable starts from a ground anchor 1,100 feet (335 meters) south of the fixed service structure, angles up and over the lightning mast, and then extends back down to a second ground anchor the same distance to the north. Lightning strikes run to ground through this cable. The mast functions as an electrical insulator, holding the cable away from the tower. The mast, with its accompanying support structure, lifts the cable 100 feet (30.5 meters) above the steel of the fixed service structure.

After rollback of the rotating service structure, Space Shuttle Atlantis can be seen atop the mobile launcher platform on Launch Pad 39A. Below the platform is the flame trench, part of the flame deflector system that insulates pad structures from the intense heat of launch.

The **emergency egress system** provides an escape route for the astronauts in the orbiter and closeout crew on the fixed service structure until the final 30 seconds of the countdown. Seven slidewires extend from the fixed service structure at the orbiter access arm level, down to the ground. A flat-bottom basket made of steel wire and heat-resistant fiber, surrounded by netting, suspends from the top of each of the seven wires. Each basket can hold up to three persons. The basket slides down a 1,200-foot (366-meter) wire to an emergency shelter bunker located west of the fixed service structure. The descent at about 55 mph takes approximately 35 seconds; a braking system using a net and drag chain stops the slowing basket at the bottom.

STS-106 Mission Specialists Richard A. Mastracchio (left) and Edward T. Lu take their seats in a slidewire basket, part of emergency egress training at the launch pad.

A sound suppression water system has been installed on the pads to protect the orbiter and its payloads from damage by acoustical energy and rocket exhaust reflected from the flame trench and mobile launcher platform during launch. The shuttle orbiter, with its payloads in the cargo hold, is much closer to the surface of the mobile launcher platform than the Apollo spacecraft was at the top of a Saturn V or Saturn 1B vehicle.

The sound suppression system includes an elevated water tank with a capacity of 300,000 gallons (1,135,620 liters). The tank is 290 feet (88 meters) high and is located adjacent to each pad.

The water releases just prior to the ignition of the shuttle engines, and flows through 7-foot-(2.1-meter-) diameter pipes for about 20 seconds. Water pours from 16 nozzles atop the flame deflectors and from outlets in the main engines' exhaust hole in the mobile launcher platform, starting at T minus 6.6 seconds.

By the time the solid rocket boosters ignite, a torrent of water will be flowing onto the mobile launcher platform from six large quench nozzles, or "rainbirds," mounted on its surface.

The rainbirds are 12 feet (3.7 meters) high. The two in the center are 42 inches (107 centimeters) in diameter; the other four have a 30-inch (76-centimeter) diameter.

The peak rate of flow from all sources is 900,000 gallons (3,406,860 liters) of water per minute at 9 seconds after liftoff.

Acoustical levels reach their peak when the space shuttle is about 300 feet (91 meters) above the MLP, and cease to be a problem at an altitude of about 1,000 feet (305 meters).

Solid Rocket Booster Overpressure Suppression System: This is part of the sound suppression water system. It alleviates the effect of a reflected pressure pulse that occurs at booster ignition. Without the suppression system, this pressure would exert significant forces on the wings and control surfaces of the orbiter.

There are two primary components to this acoustic energy suppression system. A water spray system provides a cushion of water which is directed into the flame hole directly beneath each booster. A series of water bags stretched across the flame holes, providing a water mass to dampen the reflected pressure pulse, supplements this effort.

Used together, this water barrier blocks the path of the reflected pressure wave from the boosters, greatly decreasing its intensity.

In the event of an aborted mission, a post-shutdown engine deluge system will cool the aft end of the orbiter. It also controls the burning of residual hydrogen gas after the shuttle's main engines have been shut down with the vehicle on the pad. There are 22 nozzles around the exhaust hole for the main engines within the mobile launcher platform. Fed by a 6-inch-diameter (15-centimeter-) supply line, water flows at a rate of up to 2,500 gallons (9,463.5 liters) per minute.

Main Engine Hydrogen Burnoff System: Hydrogen vapors that occur during the main engine start sequence expel into the engine nozzles just before ignition. This action results in a hydrogen-rich atmosphere in the engine bells. To prevent damage to the engines, six hydrogen burnoff pre-igniters have been installed in the tail service mast. Just before main engine ignition, the pre-igniters activate. They then ignite any free hydrogen in the area below the engine bells. This avoids rough combustion at main engine start.

The **Propellant Storage Facilities** are located at both pads. A 900,000-gallon (3,406,860-liter) tank at each pad stores the liquid oxygen, which is used as an oxidizer by the orbiter's main engines. These ball-shaped vessels are actually huge vacuum bottles. They maintain the super-cold liquid oxygen at temperatures of minus 297 degrees F (minus 183 degrees C). Two pumps that supply 1,200 gallons (4,540 liters) of oxidizer per minute each transfer the liquid oxygen from the storage tank to the orbiter's external tank.

Similar 850,000-gallon (3,217,590-liter) vacuum bottles at the northeast corner of the pads store the liquid hydrogen for the orbiter's main engines. Pumps are not required to move the liquid hydrogen from the storage tank to the orbiter's external tank during fueling operations.

First, a small amount of liquid hydrogen vaporizes. This action creates a gas pressure in the top of the tank that moves the extremely light fuel through the transfer lines.

The 290-foot water tank at right of the launch pad holds 300,000 gallons of water that flow through outlets and flame deflectors in the mobile launcher platform just before launch to act as sound suppression. The confluence of the water and intense heat and flames from the three main engines and solid rocket boosters creates the billowing steam seen (flowing left from the main engines and right from the boosters) during this launch of Space Shuttle Atlantis April 8, 2002, on mission STS-110.

A large, round tank that is actually a huge vacuum bottle stores the supercold liquid hydrogen at the launch pad. A similar round vessel holds the liquid oxygen. The liquid propellants flow to the orbiter's main engines.

Then vacuum-jacketed transfer lines carry the supercold propellants to the mobile launcher platform, where they feed through the orbiter into the external tank through the tail service masts.

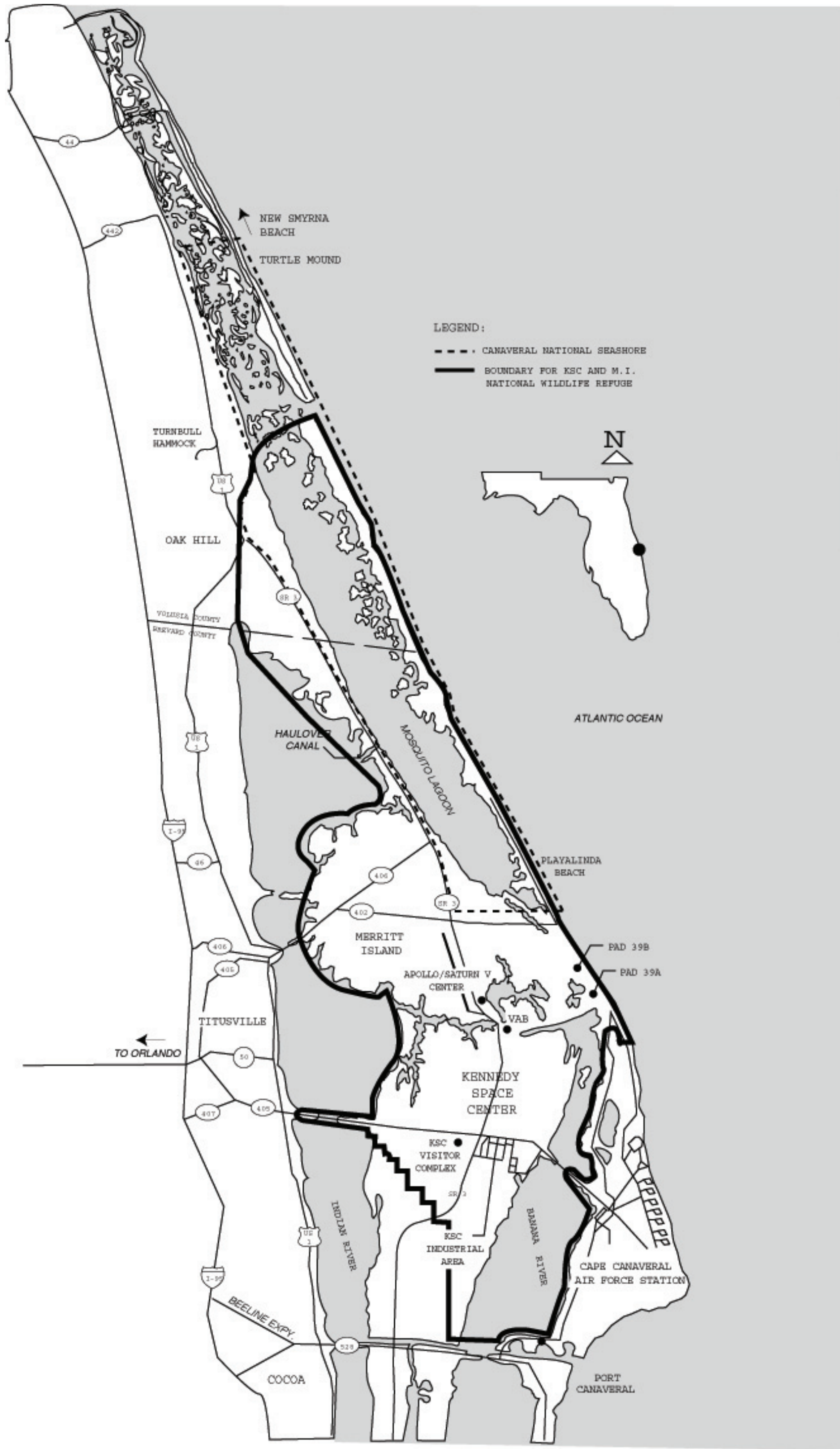
Hypergolic propellants used by the orbiter's orbital maneuvering engines and attitude control thrusters are also stored at the pad in well-separated areas. A facility located on the southeast corner of each pad holds the fuel, monomethyl hydrazine. A facility on the southwest corner stores the oxidizer, nitrogen tetroxide.

These propellants feed by transfer lines to the fixed service structure and continue to the rotating service structure's hypergolic umbilical system, with its three pairs of umbilicals attached to the orbiter.

Pad Terminal Connection Room

Elements located in the Pad Terminal Connection Room provide the vital links between the launch processing system in the Launch Control Center, the ground support equipment and shuttle flight hardware at the pad. This room lies below the pads' elevated hardstand.

At the launch pad, each side of the orbiter's engine nozzles is connected to a tail service mast. The mast provides propellant-loading umbilicals and establishes connections to ground support equipment.



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